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HAWAII AGRICULTURAL EXPERIMENT STATION,
E. V. WILCOX, Special Agent in Charge.

Bulletin No. 32.

THE PAPAYA IN HAWAII.

BY

J. E. HIGGINS,
Horticulturist,

AND

VALENTINE S. HOLT,
Assistant in Horticulture.

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *June 30, 1913.*

SIR: I have the honor to submit herewith and recommend for publication, as Bulletin No. 32 of the Hawaii Agricultural Experiment Station, a paper on the Papaya in Hawaii, by J. E. Higgins, horticulturist, and V. S. Holt, assistant in horticulture. This paper contains the results of investigations at this station and a consideration of the literature of the subject as related to the work of the station.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON, *Secretary of Agriculture.*

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THE PAPAYA IN HAWAII.

INTRODUCTION.

Excepting the banana, there is no fruit grown in the Hawaiian Islands that means more to the people of this Territory than the papaya, if measured in terms of the comfort and enjoyment furnished to the people as a whole. The papaya is the almost universal breakfast fruit in Hawaii, enjoyed alike by rich and poor, and is recognized as one of the most wholesome fruits wherever it abounds. It grows so readily, with so little care, in such variety of soils and conditions, with no serious diseases or insect pests; it occupies so little space and matures a crop so quickly that it is to be found in nearly every door-yard and garden. The taste for the papaya seldom needs to be acquired, although appreciation for it increases with familiarity, and there are few fruits which can be indulged in so regularly without wearying the taste. All this applies to the really good papaya, for there are few fruits which vary more widely in flavor than these.

Because of its importance as a home fruit as well as one for local market in Hawaii; because of its possibilities in manufactured products, and, for some countries, in export; because of the need of establishing good varieties that can be depended upon to reproduce themselves; because of inquiries relating to methods of culture and to the possibilities of papain production; and because of the importance of certain scientific problems which are referred to in the last part of this publication, the Hawaii Experiment Station has been pursuing certain investigations of this plant and offers this paper as a contribution to the limited literature of the papaya.

PART I. CULTURE AND USES.

NATURAL REQUIREMENTS.

The papaya is a tropical plant and does not prosper under any other than tropical conditions. Just outside the Tropics it is grown as a beautiful ornamental that occasionally yields fruit, but it is never a success as a fruit producer. In Hawaii it thrives best below 1,200 feet altitude, luxuriating and producing its best fruits in the warmest localities. The effect of the lack of heat in the cool season is marked by a retarding of the process of maturing and ripening fruit and to

a less degree by a slower growth and the setting of less fruit. Fruit produced at high altitudes or that maturing during very cool weather is frequently inferior in flavor. Reference will be made later to the tendency of cold weather to produce a fruiting condition in the male tree.

In regard to rainfall and moisture requirements, the plant is able to adapt itself to a wide range of conditions, and when established suffers much less from a shortage of water than the orange or the avocado, but makes beneficial use of large amounts if supplied. Yet withal, it is one of the most insistent plants in matters of drainage. In water-logged soils the papaya makes a spindling growth and drops its lower leaves prematurely while the remaining foliage becomes yellow, the whole plant indicating an unhealthy condition.

There are few, if any, soils in which the papaya will not grow if aeration and drainage are adequately supplied. Most of the plantings at this station are upon soils regarded as unsuitable for other fruit trees, and upon which the avocado is a failure. It is true that these soils are fairly well supplied with potash, being black sand or volcanic ash in the early stages of disintegration. They are very porous, permitting a perfect drainage and aeration. Rich soils give correspondingly better and more permanent results if they permit of the free passage of water and the entrance of air.

PROPAGATION.

The papaya is usually propagated by seeds. Very little systematic effort has been made to establish varieties that can be depended upon to reproduce their characters, as has been done with so many cultivated plants. This matter is more fully discussed in the second part of this bulletin, but it may be here stated that judicious selection is as promising of results as with other plants, and, therefore, seeds from good trees only should be planted. This station has been breeding papayas for a short time and while seed can not yet be regarded as wholly dependable to produce the variety some seed is available in small quantities to those who have suitable facilities for its growth.

The seed is taken from the fruit, washed to remove the outer gelatinous coat, and dried. It may then be stored in glass bottles if it is not desired to plant it at once, and it will retain its viability for several years if not attacked by insects. It is best to plant the seed in a well-drained, porous soil in flats or boxes, covering them about a half inch deep. In from 2 to 6 weeks the seedlings should appear, germination being hastened by heat. In the open in cool weather the time will not be less than a month, but in a warm greenhouse it may be shortened to 2 weeks. In about a month after germination the seedlings should be large enough to be transferred to pots in which they should remain for another month before being placed in the

orchard or garden. Such plants should not wilt when they are set out.

In planting, holes 2½ feet in each dimension should be dug and refilled. If the trees are to be planted in a lawn, holes 3½ feet in diameter will be better. The distances between trees should be about 10 feet in each direction. Shading is not usually necessary with plants hardened in pots, but in a windy locality some protection from excessive loss of moisture is desirable. At this time, particularly in the winter season, precautions should be taken to prevent the destruction of the plants by cutworms (see p. 44).

Recently considerable attention has been given to propagating the papaya by asexual means. For some time cuttings from the young shoots on the side of the tree have been made to form roots under suitable conditions of temperature and humidity, but this has not been regarded as a practical means for general propagation. Prof. P. H. Rolfs was probably the first to apply successfully any form of grafting to this species. His method, as reported in a letter to Dr. E. V. Wilcox of this station, was inarching, the experiments having been conducted when Prof. Rolfs was in charge of the Subtropical Laboratory of the U. S. Department of Agriculture, at Miami, Fla. "The inarching was made by cutting away a considerable portion of the branch, as well as a considerable portion of the stock. The two were then brought together and held firmly in place with raffia. In the course of a few weeks the two had made a very good union."

Credit is due to Mr. David Fairchild and Mr. Edward Simmonds for having first applied cleft grafting to the papaya. In a recent circular [1] their method is described, which consists in applying scions from side shoots to seedlings about two months old, or less. The stock is cut off with a horizontal cut, and the usual cleft is made with a very sharp knife.

Both of these methods have been tried at the Hawaii station, and successful unions have been effected. It seems not improbable that some of these methods of asexual propagation may prove valuable in prolonging the existence of superior trees for breeding purposes. It is claimed that trees so propagated fruit more quickly than seedlings, which is in accord with the general principle of budded and grafted stock. This would be an advantage in subtropical countries where a few weeks may make a great difference in the fruiting season.

TRANSPLANTING LARGE TREES.

When necessity demands, it is possible to move quite large trees. There are reports of trees having been moved when two or three years old. The writers have not had occasion to attempt the transplanting

[1] U. S. Dept. Agr., Bur. Plant Indus. Circ. 119.

of papaya trees more than 5 or 6 feet high. These have been successfully moved on several occasions during the last 12 years by taking up as much as possible of the root system intact and cutting off the leaf blades, except those at the top not fully developed, a part of each petiole or footstalk being left attached to the trunk.

IRRIGATION.

While the papaya will produce good fruit with a quite limited supply of water, it responds freely to liberal irrigation on well-drained soils, and under such conditions yields larger fruits and heavier crops. It is impossible to state any rule which can govern the amount of irrigation under the widely different conditions existing, but in general it may be said that less water than is required for the orange will suffice. When the young plants are set out they require watering every day or two for a few weeks, because the surface soil in which are the roots dries out very rapidly. In the few small plantations in the dry districts near Honolulu water is applied to established trees in ditches or depressions between the rows.

FERTILIZERS.

No exact data are available to show the actual fertilizer requirements of the plants. This station has used successfully on young trees the following fertilizer formula:

	Pounds.
Superphosphate (acid phosphate)	800
High grade sulphate of potash	315
Nitrate of soda	250
Sulphate of ammonia	190
Black sand (volcanic ash)	445
Total	2,000

This has been applied at the rate of 1 pound per tree at planting time, thoroughly mixed with the soil in the hole prepared for the tree, and as a surface dressing six months later.

PRUNING AND CHANGE OF SEX.

There is little necessity for pruning papaya trees. Some plants show a tendency to send out side shoots, and it is advisable to remove these or the nourishment will be diverted from the fruit crop on the main trunk. When the latter has borne for two or three years it may be cut down, and some of the side shoots may be allowed to form a new top, which will continue the bearing life of the tree and produce easily accessible fruits.

Changing the sex of a male tree has at times been brought about by severe pruning. Removing the terminal bud or even cutting off the whole top below the leaves has been known to bring about this

change (see p. 26), but such treatment can not be depended upon to do so.

In Plate X, figure 1, is shown a staminate tree which, so far as observed, produced no fruit-bearing flowers. It was cut to a stump about 6 or 8 feet high, and soon sent out side branches upon which only pistillate (female) flowers have been found.

THINNING THE FRUITS.

There is a great variation in productivity among papayas. In some there is a cluster of several fruits in the axil of every leaf, while in others only a single fruit is to be found at each axil, and still others may have only a few fruits scattered up and down the trunk. When the fruits are borne in clusters it frequently becomes necessary to thin them out because there is not sufficient space for their development, and if not thinned they crowd each other into distorted shapes. The thinning may be easily and quickly performed with a knife when the fruits are young.

ARTIFICIAL FEEDING.

A number of tropical agricultural journals have reported what purports to be an instance of artificial nutrition in the papaya, credited to Mr. Jesse, of Jolo, Philippine Islands.[1] In this treatment it is said that a hole is bored in the trunk about 6 inches from the ground, 1 inch deep, and of a diameter "slightly larger than the red rubber tubing obtainable at drug stores." Fill a quart bottle half full of sugar and dissolve in water. When the sugar is dissolved, connect the bottle with the hole in the tree by the rubber tubing. In 24 hours the tree is supposed to have absorbed the contents of the bottle.

RENEWING THE PLANTINGS.

Papaya trees are of short life. Specimens have been known to continue in bearing for 15 years, but the period of profitable productivity is usually not over 3 or 4 years. Trees can be grown so easily and so quickly that it is the custom to renew the plantings often.

THE FRUIT CROP.

The first ripe fruits may be expected in about a year from the time when the plants are set in the orchard or garden, and thereafter fruits and flowers in all stages of development may be in evidence at all times of the year. In the cool season the fruits are slow in ripening, thus causing a short crop and high prices for a month or two. At this time the growers often receive 3 to 3½ cents per pound for fruit which in summer would not bring more than 1 or 1½ cents.

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[1] Trop. Agr. and Mag. Ceylon Agr. Soc., 37 (1911), No. 1, pp. 32, 33.

Papayas for market should be picked very soon after they show the first yellowing. In the case of some trees, particularly of the long fruited varieties, the necessary maturity is indicated by light green color. Certain varieties become ripe enough for serving while showing little yellow coloring. Papayas are so large and heavy that it is difficult to get them safely to the consumer if they have begun to soften when picked. Great care is necessary to avoid bruising. For local market they may be carried on the body of a spring wagon provided with straw, excelsior, or similar material, or, for more than one tier of fruit, racks may be provided.

In the fruit-marketing investigations conducted by this station it was found that papayas can be shipped long distances. They were taken to San Francisco with very small losses and were marketed in small quantities from San Francisco, in Portland, Seattle, Tacoma, and Vancouver, B. C.[1] The chief results may be summarized as follows:

Fruits, preferably of the long varieties, should be gathered when they show the first indications of ripening. They should be wrapped in paper and surrounded by a sleeve or cylinder of crimped strawboard before being placed in the single-tier crates in which they are shipped. It is important to get them into refrigeration as soon as possible. The crates used in these experiments are illustrated in Plate II. They proved satisfactory in dimensions but could be made of lighter material.

It is well known locally that papayas, with all other fruits from Hawaii, except bananas and pineapples, are now prevented from being shipped to California because of the prevalence of the Mediterranean fruit fly in these islands. These directions therefore are repeated at present, not for any local applicability, but for whatever use they may be in other tropical countries.

VARIETIES.

Strictly speaking there are few, if any, varieties of papaya. A variety, in the case of seed-propagated plants, is a described and named form, having certain well-recognized characters which are reproduced in the offspring with a reasonable degree of accuracy and usually maintained by artificial pollination or by segregation to prevent crossing with pollen from other varieties or species. Such work, so far as has been learned, has not been conducted with the papaya long enough to justify the naming of any form and thus giving to it the rank of a variety. This station has now in hand a line of selections and close pollinations which it is hoped may yield some forms sufficiently distinct and stable to merit naming. At present the station forms are designated by numbers only.

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[1] Hawaii Sta. Bul. 14.

In a less exact sense such terms as "long variety" and "round variety" are sometimes used. These are intended to designate respectively the perfect-flowered form in which both male and female organs are in the same flower, and the commoner form in which there are male and female trees. This subject will be discussed more at length in the last part of this bulletin. For those who may not care for the more technical part of the subject, it may be said that the present endeavor is toward the former type and the elimination of the male trees which in the latter type frequently form 75 to 85 per cent of the trees, and are indistinguishable from the females until flowering time, and thus are wasteful of space and time. Seeds of the long variety generally produce a very large majority of fruit-bearing trees. Plate I shows a view in an orchard in which nearly every tree is bearing fruit.

THE PAPAYA AS A FOOD.

Perhaps the most frequent use of the papaya is as food, although almost all parts of the plant are utilized in some way.

The general composition of the papaya fruit is shown by the following analysis:[1]

	Per cent.
Water	90.75
Protein	.80
Fat	.10
Fiber	1.09
Nitrogen-free extract	6.32
Ash	.94

Reference has been made above to the nearly universal use of the ripe papaya in the Tropics as a breakfast fruit. For this purpose it is cut lengthwise into portions and the seeds removed. The placenta with the seeds attached may often be removed without scraping the flesh, which is thus left in the most attractive form for serving. Many prefer the choicest fruits without other flavoring of any kind, but a little juice of the lemon or the lime is a favorite accompaniment, while a few prefer salt and pepper or even sugar. The green fruit when fully grown may be cooked as summer squash, for which it affords a very good substitute. The ripe fruit is used in making papaya glacé.

The following recipes, taken from a book recently published, give some directions for the use of this fruit:[2]

China Orange and Papaya Marmalade, No. 1.

To 1 measure papaya allow ½ measure China oranges. Wash oranges well. Squeeze out seeds and juice. Put skins through a meat chopper and add to the juice, strained free from seeds. Add papaya pulp cut in small pieces and boil all together; then add as much sugar as pulp. Boil again for 15 or 20 minutes.

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[1] Maine Sta. Bul. 158.

[2] Jessie C. Turner and Agnes B. Alexander. How to Use Hawaiian Fruits. Honolulu, 1910, pp. 17, 42, 43.

China Orange and Papaya Marmalade, No. 2.

To 6 cups papaya cut in small pieces add ½ cup China orange juice. Boil 15 minutes and add half as much sugar as pulp. Boil again for 15 or 20 minutes.

Stewed Papaya, No. 1.

2 cups diced papaya
½ cup sugar
¼ cup water
Juice 2 lemons

Cut papaya in dice and stew with sugar, water, and lemon juice ½ hour. Serve in sherbet glasses as a first course for luncheon, or a dessert. Can use 4 China oranges in place of lemons.

Stewed Papaya, No. 2.

Cook in the same manner as No. 1, with ¼ cup sugar and only enough water to keep from burning. Serve as vegetable.

Baked Papaya.

Cut papaya in halves lengthwise. Add a little sugar and China orange, lime, or lemon juice; or a little cinnamon in place of the juice. Bake 20 minutes, and serve immediately on taking from the oven. This is a vegetable.

Papaya Pickle.

Make sirup of 1 measure sugar and ½ measure vinegar. Add a few whole cloves and pepper corns and 2 measures of half-ripe papaya cut into small pieces. Boil until tender.

Papaya and Ginger.

Make a sirup of 1 measure ginger, ½ measure water, some finely sliced dried ginger, and a few slices of lemon. Add 2 measures half-ripe papaya sliced lengthwise, which has been previously simmered in water until clear, but not broken.

Papaya Cocktail.

Cut papaya in dice and serve in glasses with cocktail sauce and chipped ice.
Or serve with China orange, lemon, or lime juice, and little sugar in same manner.

Papaya Salad, No. 1.

On a strip of peeled papaya lay small bits of pomelo and orange. Serve with mayonnaise on separate plates, and garnish each with one or two nasturtiums and leaves.

Papaya Salad, No. 2.

Cut papaya in cubes and add 8 small Chinese onions and 5 pieces green celery chopped fine. Serve with boiled dressing.

Papaya Whip.

To 1½ cups papaya pulp add juice 1 lemon, ½ cup sugar, and beat into 2 stiffly whipped whites of eggs.

Papaya Jelly.

½ box gelatine
½ cup cold water
Juice 1 lemon
1 cup boiling water
1 cup papaya pulp
½ cup sugar

Soak gelatine in the cold water 5 minutes. Dissolve the sugar in the boiling water; add the gelatine and strain. When cool, add the papaya and lemon juice. Place on ice to harden.

Papaya Pie.

2 eggs
1 cup papaya pulp
½ cup butter
1 cup sugar
Juice ½ lemon

Make a bottom pie crust and bake. Cream butter and sugar. Add beaten eggs, lemon juice, and papaya. Pour into pie crust and bake. Make a meringue of whites of eggs and 2 tablespoonfuls sugar. Place on pie and brown in oven.

Papaya Sherbet.

Mix 4 cups papaya pulp with 2 cups sugar and juice of 2 lemons, and freeze.

MEDICINAL AND OTHER USES.

Papaya bark is used in the manufacture of ropes. Nearly all parts of the plant are credited with some medicinal value. The roots afford a nerve tonic. The seeds are said to be anthelmintic, emmenagogic, and carminative. They are also eaten as a delicacy and as a quencher of thirst. The ripe fruit finds a place as an ingredient in certain sirups and elixirs, which are said to be expectorant, sedative, and tonic.

The most important medicinal property of the plant is found in the milky juice. This is used by the natives of the Tropics in the treatment of eczema, warts, intestinal worms, ulcers, and many kinds of foul sores, in diphtheria to dissolve the false membrane in the throat, and for numerous other ailments.

The ripe fruit is used as a cosmetic, a slice of it being rubbed upon the skin to remove freckles and other blemishes. The green fruit and the leaves are employed as soap to remove stains from clothing.

No single use of the papaya, except for food, is so common in the Tropics as that of the milky juice in rendering tough meat tender. For this purpose a slice of the green fruit, rich in juice, is rubbed over the tough flesh, or the latter is dipped for a few minutes in a solution of the juice. Sometimes a piece of the green fruit is put in the water in which the meat is boiled.

Another practice is to wrap the meat in papaya leaves overnight, or even to hang it in the papaya tree. The feeding of green papayas to hogs is reported to make the pork tender. Some of these practices are of doubtful efficacy. Some writers recommend mixing ginger with the juice when it is to be applied to meat.

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PAPAIN.

Most of the effects of papaya juice referred to above are due to the presence in the juice of an active principle which has been named "papain."[1] This was first investigated by Wurtz and Bouchut, in 1879.[2] It may be separated from the juice by means of alcohol, and either the juice itself or the separated ferment is now well known to possess the power of digesting proteids.[3]

The medicinal use of this ferment has grown to considerable proportions and has given rise to a not insignificant trade in papaya juice. Exact data of imports of dried papaya juice in the United States are not available, but those closely in touch with the manufacturing end of the business estimate the value of the importations at about $75,000 to $80,000. The price paid varies from $1.50 to $3 per pound. The product is often adulterated and also may in part lose its efficacy by careless methods of preparation. It therefore is bought on sample tested to determine its digestive properties. The term "papain," which primarily refers to the ferment, has been extended in its use and now is applied to the dried juice also, either crude or in various stages of manufacture.

The chief sources of supply for the American trade are the West Indies and Ceylon. Some years ago Jamaica maintained an industry of some importance in collecting and preparing the juice for market, but it is no longer continued. Later the business grew up in the island of Montserrat, which became the chief producer in the West Indies, whose papain brought a much higher price than the average product from Ceylon. Opinion among large manufacturers seems to be divided on the question of the present relation of supply and demand, some stating that the consumption of the drug is on the increase and the prospect good for marketing larger quantities, while others affirm that the only means of extending the market now would

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[1] Written also papaïn and papaine.

[2] Compt. Rend. Acad. Sci. [Paris], 89 (1879), p. 425. Wurtz, ibid., 90 (1880), p. 1379; 91 (1880), p. 787.

[3] Readers interested in a study of the chemical and physiological properties of papain may consult the following references:

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Amer. Jour. Pharm., 73 (1901), Nos. 6, p. 272; 7, p. 336; 8, p. 383. Reprinted in Bul. Dept. Agr. Jamaica, 1 (1903), No. 8, p. 181; 2 (1904), Nos. 4, p. 84; 5, p. 113; 8, p. 178.

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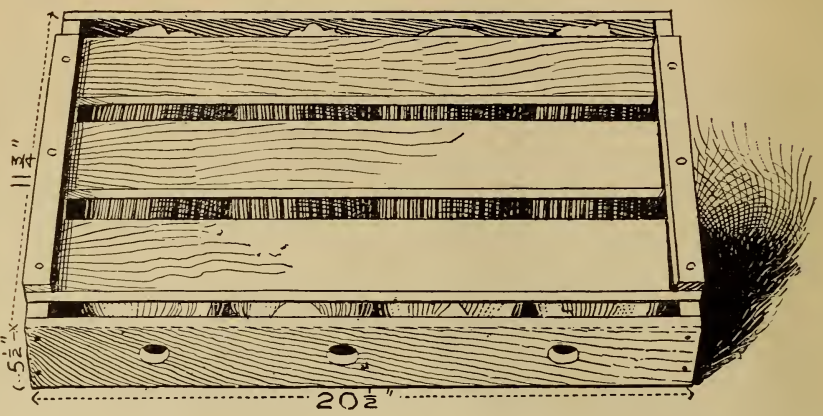
Christy, T. New Commercial Plants and Drugs. London, 1881–1886, Nos. 4, p. 38; 5, p. 59; 6, p. 66; 7, p. 67; 8, p. 67; 9, p. 40.

PAPAYA ORCHARD IN WHICH NEARLY EVERY TREE IS BEARING FRUIT.



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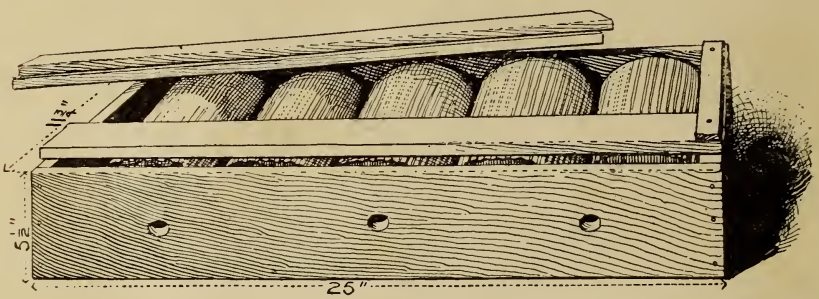

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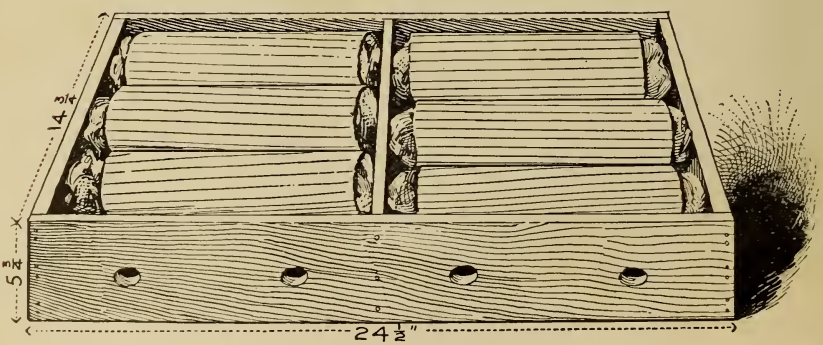

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CRATES FOR PAPAYAS.

PISTILLATE PAPAYA TREE AND FLOWER OF THE DIŒCIOUS TYPE.

FIG. 1.—MALE PAPAYA TREE.

FIG. 2.—CORREÆ TREE WITH A FEW FRUITS; STAMINATE FLOWERS TO THE RIGHT.
One flower cut open exposing stamens and rudimentary pistil.

be in the production of a more carefully prepared product, which would replace the cheaper and adulterated grades, of which considerable quantities are sold. From the fact that the prices have fallen in recent years it would not seem that the demand is very brisk. The Montserrat industry has declined to some extent.

COLLECTING AND PREPARING THE JUICE.

There are no difficulties requiring great skill in collecting and preparing the juice for market, but care is necessary. Usually only the fruits are tapped. These abound in juice, particularly when the tree is young and during warm weather after a rain. In the early morning the flow is most abundant. Very shallow incisions, not over one-eighth of an inch, are made about a half inch apart, lengthwise of the nearly mature green fruits. The tapping may be repeated several times at intervals of three or four days. Only nonmetallic instruments should be used in tapping or in collecting, for the juice acts upon metals and becomes discolored. A bone or ivory blade may be used. The flow is free at first and the liquid is caught in porcelain, glass, or earthenware vessels. Coagulation soon begins and the mass must be scraped from the surface of the fruit. In most places where the industry is conducted labor is cheap, but it would seem that a more convenient and efficient vessel could be devised which could be quickly put in place to receive the juice, permitting the operator to proceed to the next tree.

The juice must be dried promptly after it is collected or decomposition begins. As the juice flows most freely in the early morning, it is usually collected then and dried wholly or in part during the remainder of the day. Sun drying is followed to some extent, but artificial means, such as are furnished by a fruit drier or one made expressly for the purpose are preferred. In Montserrat several driers have been made for the purpose and operated by the companies buying the juice from the peasants who gather it. One form of drier is about 3 by 3 feet, and 6 feet in length. The sides and ends are of brick with an opening at one end for the flue and at the other end to admit fuel. The top is open. About a foot below the top a sheet of iron is placed and upon this an inch or two of sand to modify and distribute the heat arising from the fire beneath. The coagulated juice is spread upon brown linen stretched upon frames which are made to fit the top of the drier. The drying must be effected with low temperatures, as great heat destroys the ferment. A temperature below 100° F. is preferred by some operators. The coagulated material may be placed upon sheets of glass while drying. When dry and flaky it may be ground in a coffee mill, preferably while warm, and should

then be in the form of a white or cream-colored powder, which should be placed in bottles and tightly closed.

In the powdered form or as dried flakes it is exported to America and Europe, where it is further refined and sold as a powder or in tablet or other form, under various trade names as "papoid," "caroid," "papain," "papayotin," etc.

Little information is available as to yields. Some collectors figure upon a yearly production of 1 pound of dried latex per tree. This is probably rather a high estimate. The coagulated latex will produce about 25 per cent of its weight in dried powder which still contains from 6 to 10 per cent of moisture.[1] About one-sixth of the dried powder is papain.

PART II. BREEDING OF PAPAYA.

One of the most interesting and important features of papaya study is breeding; interesting because of the many problems which it presents, and important because of the large promise of improvement in these fruits. This part of the paper will attempt to present descriptions of some of the material at hand for such work, showing also some of the difficulties, possibilities, and limitations in papaya breeding so far as they have appeared in the work performed here.

BOTANICAL NAMES.

Before entering upon these phases of the subject a word will be in order as to the names, botanical relationships, and distribution of the species. *Carica papaya* Linn. has been designated botanically under several names as *Carica mamaja* Vellozo (Fl. Flumin., Vol. X, t. 131); *Carica hermaphrodita* Blanco (Fl. de Filipinas, Gran edicion 1879, Vol. III, p. 212); *Papaya vulgaris* A. DC. (Prodr., XV, I, p. 414); and *Papaya sativa* Lussac (Fl. des Antilles, Vol. III, p. 45, t. 10, 11).

COMMON NAMES.

The species has been known under many common names, as tree melon, melon zapote, pawpaw, papaw, lechoso, maneo, mamerio, papai, papaya, etc. In English-speaking countries the name papaya is taking the place of tree melon and pawpaw, both of which are misleading. It is particularly desirable that the use of the name papaw to designate the fruit should be dropped, since its application to a wholly unrelated species, *Asimina triloba*, is well established. The name papaya, which now should be adopted generally, is believed to be of Carib origin, and is heard among the descendants of these aboriginal peoples in various forms, as "mapaya" and "mamaya,"

[1] F. B. Kilmer. The Story of the Papaw. Amer. Jour. Pharm., 73 (1901), Nos. 6, pp. 272–285; 7, pp. 336–348; 8, pp. 383–395.

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Grant. H

being supposed by Humboldt to be a derivative of "mapa," meaning honey.[1]

BOTANICAL RELATIONSHIPS.

The plants of the genus Carica have been referred to by different botanists to the families Papayaceæ, Passifloreæ, and Cucurbitaceæ. This and the genus Jacaratia now constitute the family Caricaceæ.[2] Carica has been divided into the three subgenera or sections, Vasconcellea, Hemipapaya, and Eupapaya, embracing 22 known species, all of American or West Indian origin, the genus being represented from Argentina to Mexico and in the Antilles. Of the home and probable origin of *C. papaya*, mention will be made later.

DESCRIPTIONS OF FORMS OF PAPAYA.

The above will serve to indicate the general botanical position of the papaya and its relatives. Breeding at this station has been confined chiefly to the one species of this genus *C. papaya*, *C. peltata*, and *C. quercifolia* having been the only others used. Some descriptions of the forms in which the papaya itself occurs with reference chiefly to the distribution of the sexes and the shape of the fruit are given below.

Form 1. The first form to be considered is the ordinary female. Commonly the papaya is dicœcious. The female tree produces flowers exclusively pistillate, with no indication of even the remnants of stamens (Pl. III). At first sight they may appear to be polypetalous, since the corolla tube is greatly reduced, but closer observation reveals their gamopetalous condition. The ovaries and the resulting fruits are of various shapes, inclining to the obovoid, with a diameter somewhat shorter than the major axis, and the surface smooth or only slightly ribbed. The fruits are usually borne singly on very short peduncles in the axils of the leaves.

Form 2. The male tree (Pl. IV, fig. 1), the counterpart of that just referred to, produces only staminate flowers which, however, possess rudimentary or abortive pistils (Pl. IV, fig. 2), and hang in great profusion in cymose panicles on peduncles, 2 to 5 feet in length. The flowers, unlike those of the female tree, have a long corolla tube in the throat of which are 10 stamens arranged in two series, the one having slightly longer filaments than the other. At the base of the tube may be found a small rudimentary pistil, quite devoid of any stigma. Since all the flowers are of this type the tree abounds in pollen, but produces no fruit. In foliage and habit, other than as described, it resembles the female.

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[1] Jour. Linn. Soc. [London], Bot., 10 (1869), p. 14.

[2] H. Solms-Laubach. Caricaceæ. In Martius, Flora Brasiliensis, vol. 13, pt. 3, col. 171–196, 1889.

Form 3. Correæ of Solms-Laubach. This form is a departure from the last and is illustrated in Plate IV, figure 2. It is identical with the tree just referred to except that a few of its flowers have pistils capable of fecundation. The rays of the stigmas may be perfectly formed or one or more may be aborted, giving rise to an unsymmetrical or gibbous fruit in which the corresponding portions of the placenta have failed to develop. The ovaries of the well-formed hermaphrodite flowers incline more to the elongated and cylindrical form than those of the pistillate tree and result in correspondingly different fruits. The corolla tube is elongated as in the staminate flowers and the stamens are similarly located in the throat of the corolla, being brought into proximity with the stigmas. These bisexual flowers are larger than the staminate but in other respects are similar, except as has just been indicated. The number of such flowers varies from few to many (Pl. V, figs. 1 and 2), there being at times as many forming fruits on the long pendulous peduncles as are to be found on some pistillate trees, notwithstanding the fact that many have fallen. Often as the fruit develops the peduncle is not strong enough to sustain the weight and breaks off, such long fruit stems being poorly adapted to their work of supporting the fruit and inviting disaster from the winds.

What causes may have given rise to the formation of bisexual flowers on these otherwise male trees and to what extent such plants may be regarded as varietal in their rank may be referred to later. Here it is intended merely to point out that such forms exist and to indicate their character. This form of andromonœcious [1] papaya was described by Correa de Mello and Spruce,[2] and in honor of the former has been named by Solms-Laubach [3] form correæ.

Attention has just been called to the variations in the number of fruits produced by this form correæ. It may also be pointed out that there are many gradations in the length of the peduncles.

Form 4. Elongata, a hermaphrodite papaya (Pl. VI). This tree produces two types of flowers. One of these types is hermaphrodite and is in every way similar to a well-formed bisexual flower on the correæ form (form 3), except that it usually is larger and its pistil is more elongated (Pl. VII, fig. 1). The other type of flower is staminate and is identical in appearance with the staminate flowers already described. Because of the presence of these two types of flowers, this form has been referred to in the earlier publications of this station as the monœcious papaya.[4]

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[1] Having both staminate and hermaphrodite flowers on the same plant.

[2] Jour. Linn. Soc. [London], Bot., 10 (1869), p. 3.

[3] Die Heimath und der Ursprung des cultivirten Melonenbaumes, *Carica papaya*. Bot. Ztg., 47 (1889), Nos. 44–49.

[4] Hawaii Sta. Rpts. 1910, 1911, and 1912.

As experiments have proceeded, however, it has been discovered that the pollen from such staminate flowers, except in the case of one tree, failed to fecundate any pistils up to the present time, and it has been applied to every type of pistil found in the station collection. Since these flowers apparently do not function it seems incorrect at present to apply to this form of the papaya the term monœcious. They may rather be termed either pseudomonœcious or hermaphrodite. These remarks anticipate, to some extent, facts which will be brought out later, but are made here as an explanation of the change in terminology.

To proceed further with the description of this form, it is to be noted that the two types of flowers are found in the same cluster, as was true in the last form described, but in the present case the inflorescence is much shortened, being generally from 3 inches to 6 inches long. After the tree attains sufficient maturity a flower cluster is usually formed in the axil of each leaf, but on some trees many of these clusters produce only the staminate flowers. Not infrequently 2 feet or more of the trunk may yield no hermaphrodite flowers and consequently no fruit, leaving that portion of the trunk bare after the flowers have fallen (Pl. VII, fig. 1). There may be one or several bisexual flowers in each cluster, resulting in fruit. The fruit from this hermaphrodite flower inclines to be elongated, cylindrical, and pointed at the outer end, but the shape varies as in all papayas. The form which Correa de Mello and Spruce mention as "Chamburu"[1] and which they found in the equatorial Andes, appears to be very similar to this and may perhaps be identical.

Form 5. Sterile hermaphrodite. This may be regarded as an extreme case of unproductiveness of the form just described. It has been represented by only one tree, so far as known. This has produced no fruit. A few hermaphrodite flowers were found, but none matured fruit (Pl. VII, fig. 2). The pollen of staminate flowers was unfertile.

Form 6. Forbesii of Solms-Laubach. Forbes[2] describes a cœnomonœcious[3] form which he found at Bantam, Java, and which resembles, yet is quite different from, the form correæ described above (form 3). Solms-Laubach later described the same form[4] which he found in another part of the same island. To this he applied the name forbesii. Briefly stated, the most striking characters of this plant are as follows: On the long, pendulous peduncles, characteristic of the male tree, this plant produces its three types of flowers, staminate, pistillate, and hermaphrodite. The staminate are identical

[1] Jour. Linn. Soc. [London], Bot., 10 (1869), p. 11.
[2] H. O. Forbes. Jour. Bot. [London], n. ser., 8 (1879), p. 313.
[3] Having male, female, and hermaphrodite flowers on the same plant.
[4] Bot. Ztg., loc. cit.

with those of the ordinary male tree and the pistillate with those of the female tree, but the hermaphrodite differ from those described above (form 3). These have a very much shortened corolla tube, as in the case of the pistillate flower, the lobes being divided almost to the base of the ovary. On the edge of this short tube, quite near the base of the ovary, are attached only five stamens, and these are supplied with long filaments, which rest in furrows between the lobes of the ovary. These lobes are united at the base, but often separable at the upper ends. The resulting fruit is deeply furrowed.

This form of the papaya has not been seen in Hawaii by the writers, although thousands of plants have been under observation at the experiment station and in other parts of the islands. This is rather remarkable when it is remembered that the next form closely resembling it is not at all rare in Hawaii.

Form 7. Pentandria. This form produces hermaphrodite flowers of the same type as those just described (form 6). They have the corolla tube reduced to almost negligible length and the 5 stamens inserted on long filaments on this tube, near the base of the ovary (Pl. VIII, inset). The ovary is deeply furrowed, with the stamens lying in the grooves between the lobes, thus giving rise to a deeply furrowed fruit. There are also staminate flowers of the ordinary type, and these are born with the hermaphrodite in short clusters as in the case of form 4.

Form 8. This is the coexistence of the forms 4 and 7 in the same plant (Pl. VIII). The staminate flowers of the cluster are the same as in all cases, but the two forms of hermaphrodite flowers occur side by side in the same plant and give rise to correspondingly different fruits.

Form 9. Intermediates. Here, in still other monœcious or hermaphrodite plants, are to be found almost all possible combinations of the characters of hermaphrodite flowers of the forms 4 and 7 (Pl. IX, fig. 1). The corolla may be intermediate in form between the long tube and the short. The stamens may be long, short, or intermediate, and may be attached at any one of several points on the corolla or even on the lobes of the ovary. The stamens may be from five to ten in number. The ovary is often misshapen, the lobes being only partly united, resulting in a distorted fruit. Occasionally a flower may be of the form 4 on one side and of the form 7 on the other.

Form 10. A curious andromonœcious form has recently been observed at this station. Many hermaphrodite flowers of various characters, as described above, are found on the plant, but the most curious character is the bearing of ovules on the stamens of some of these hermaphrodite flowers. With respect to its long peduncles

and in general appearance this form is the same as the male or the hermaphroditic males forbesii and correæ.

Form 11. Ernstii of Solms-Laubach. From the description given by Ernst[1] this appears to represent the coexistence on the same tree of pistillate flowers and of hermaphrodite flowers of the same characters as those of form 4. No staminate flowers were found by Ernst on such trees. He states: "Papaya has three different kinds of flowers—staminiferous, pistilliferous, and hermaphrodite. The latter two are found on the same tree, whereas the stamen-bearing flowers grow exclusively on distinct individuals." He found hermaphrodite flowers "on all the female trees examined, though never in great numbers." In his description these hermaphrodite flowers are stated to be gamopetalous (in contradistinction to the pistillate, which he regarded as polypetalous) and to possess an ovoid corolla tube in the throat of which the stamens are inserted. This distribution of the sexes has not been noted in Hawaii.

Form 12. A tree similar to the above but bearing staminate flowers as well as pistillate and hermaphrodite was seen by one of the writers a few years ago at this station. Whether the pollen from the staminate flowers was incapable of fecundating any pistil was not determined.

Form 13. Pistillate and staminate flowers on the same tree. Recorded by Iorns (see p. 25).

SUMMARY OF FORMS.

To summarize briefly, there may be said to be the following forms:

1. The female of the dicœcious papaya.
2. The male of the dicœcious papaya.
3. The correæ form of andromonœcious papaya, with its elongated corolla tube and 10 stamens in the throat; flower clusters and other characters like male.
4. The elongata form with its hermaphrodite flowers like those of correæ and its staminate flowers nonfunctioning; flower clusters short; fruits elongated, tending to cylindrical shape.
5. The sterile hermaphrodite, similar to 4, but without fruits.
6. The forbesii form of andromonœcious papaya, with its stamens in the hermaphrodite flower reduced to five in number, and these attached by long filaments to the shortened corolla tube near the base of the ovary; flower clusters and other characters like male.
7. The pentandria form with its hermaphrodite flowers like those of forbesii, staminate flowers nonfunctioning; flower clusters short; fruit generally club-shaped or obovate and furrowed.
8. The coexistence of forms 4 and 7 in the same plant.

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[1] A. Ernst. Jour. Bot. [London], 4 (1866), pp. 81–83.

9. Intermediates combining in various ways the characters of forms 4 and 7.

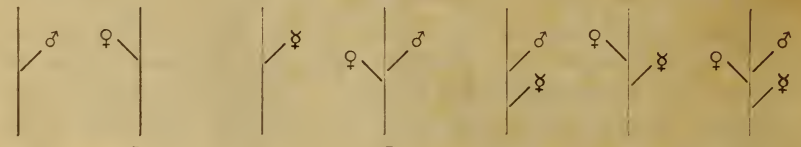
10. Andromonœcious with misplaced ovules.

11. Ernstii. Pistillate and hermaphrodite flowers on the same tree, but no staminate flowers.

12. Pistillate, hermaphrodite, and staminate flowers, with short peduncles, on the same tree.

13. Pistillate and staminate flowers on the same tree.

Disregarding the nonfunctioning staminate flowers of most elongata, it will be seen that there are represented all the possible combinations of staminate, pistillate, and hermaphrodite flowers and individuals. Representing the three elements by *a*, *b*, and *c*, the seven possible distributions would be as follows: *a*, *b*, *c*, *ab*, *ac*, *bc*, and *abc*. Represented diagramatically with the usual signs these would be as indicated below:



a is represented by form 2.

b is represented by form 1, also in most of the progeny of stocks of forms 3, 4, 6, 7, and perhaps others.

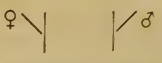
c is represented by forms 4, 7, 8, 9.

ab is represented by form 13.

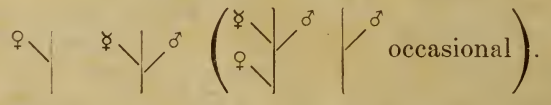
ac is represented by forms 3, 6.

bc is represented by form 11.

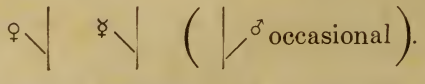
abc is represented by form 12 and occasionally by forms 3 and 6.

Seeds of form 1 will produce a population whose formula may be written thus: 

The stocks of forms 3 and 6, expressed in formula may be:



The formula for stocks of forms 4, 7, 8 and 9 would be:



Seeds of forms 11 and 12 have not been planted and the formulas for the progeny can not be stated.

Fig. 1.—Correæ Tree Bearing Only Two or Three Fruits.

Fig. 2.—Correæ Tree Bearing Many Fruits.

ELONGATA TREE AND FRUIT.

FIG. 1.—ELONGATA TREE WITH LONG BARE SPACES, AND ELONGATA HERMAPHRODITE FLOWER.

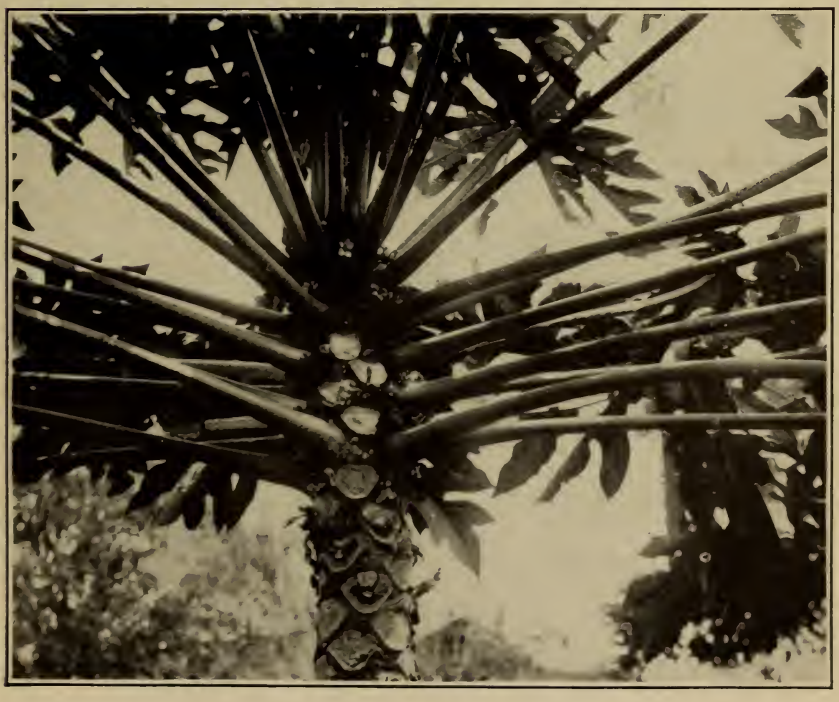
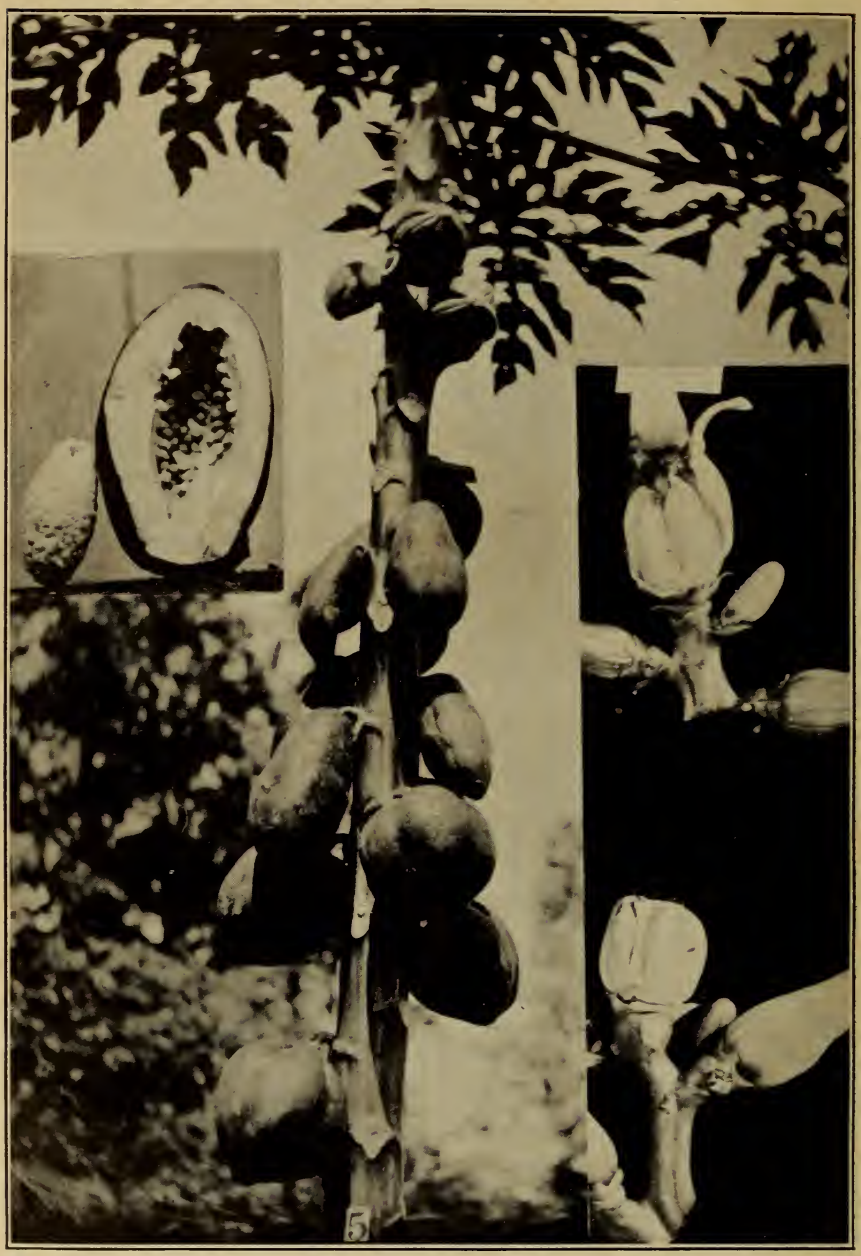


FIG. 2.—STERILE HERMAPHRODITE TREE.



ELONGATA AND PENTANDRIA FRUITS ON THE SAME TREE, PENTANDRIA FLOWERS, AND A FRUIT WITHIN A FRUIT.

FIG. 1.—INTERMEDIATE FORMS.

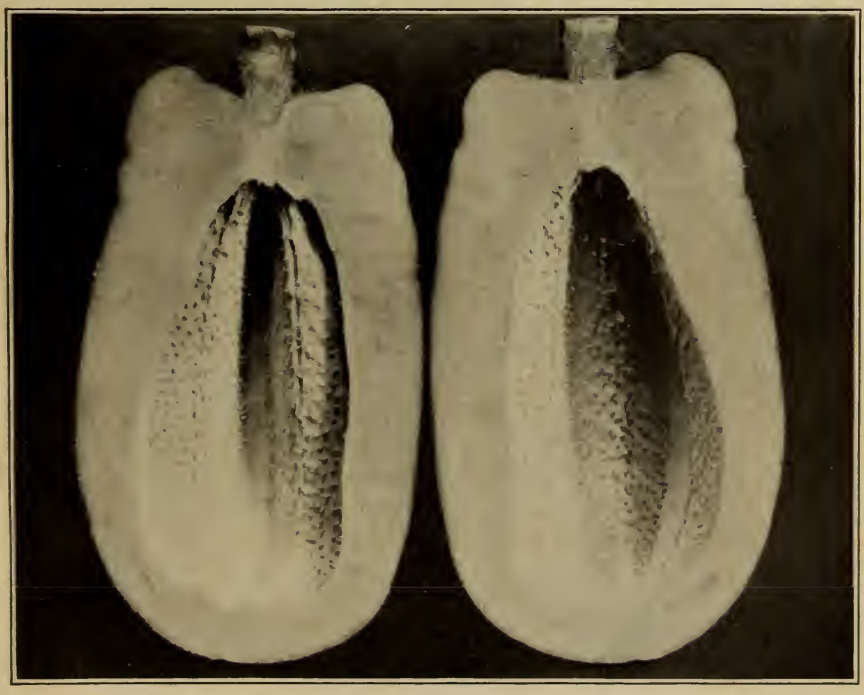


FIG. 2.—AN EXAMPLE OF PARTHENOCARPIC DEVELOPMENT.

Fig. 1.—A Papaya Tree Changed from Male to Female by Pruning.

Fig. 2.—Pistillate Flower with Elongata Form of Ovary.

SIGNIFICANCE OF THE FORMS.

It will be seen at once that many of these "forms" are merely an expression of the different manner of the distribution of the sexes, but some are distinct and have a very practical bearing upon the subject of breeding. Perhaps the most important are the male and female of the diœcious papaya, by far the most common, and to many the only familiar papaya; the two andromonœcious forms, correæ and forbesii; and the two hermaphrodite forms, elongata and pentandria. There are mentioned in the above list of twelve forms and methods of distribution of the sexes only those which have been seen in Hawaii, and two other forms, forbesii, which have been so fully reported upon by Forbes and by Solms-Laubach, and ernstii, by Ernst.

CHANGE OF SEX.

It is a fact worthy of note that some of these forms are not constant. One may assume the rôle of another. Perhaps the most primary change of sex which takes place is to be observed in the appearance of hermaphrodite flowers on trees that have previously produced only staminate inflorescence. That is, form 2 may pass into form 3 or form 6. Not only is it known that such changes take place, but the conditions which may bring them about have been under observation. This "fruiting of the male papaya" takes place most freely in cool climates outside the Tropics or at high altitudes. In Hawaii it may be seen that these trees fruit more abundantly on the mountains than near the sea level. Information received by correspondence with experiment stations and botanic gardens in many parts of the world, in reply to direct inquiry, have confirmed this conclusion. In torrid climates the fruiting of the male is rare. It is to be remembered in this connection that all the staminate flowers of the male trees possess an undeveloped or an abortive pistil. The only change in the cases mentioned consists in the development of this pistil.

The late M. J. Iorns [1] reported the appearance of female flowers on male trees as a result of the removal of the terminal bud. In the popular literature of the papaya there are many references to the acquiring of fruit-bearing habits by the male tree, due supposedly to some injury, such as the removal of the terminal bud or the breaking of the roots in transplanting old male trees. It is an interesting and suggestive fact that none of these methods of treatment bring about the results unfailingly, and there appear to be other conditions entering into the problem. Iorns undertook his experiments in part to disprove an idea prevalent among the native Porto Ricans to the

[1] Science, n. ser., 28 (1908), No. 708, pp. 125, 126.

effect that this change would be brought about if the terminal bud be removed during a certain phase of the moon. Some of his trees so treated showed the change but others did not. Those treated at fairly definitely recurring periods, however, were the specimens which appeared to undergo the change. He reached the conclusion that other conditions than the loss of the terminal bud must be present, and suggested that the trees may pass through cycles of development and be subject to this change only at certain times. It is a well-known fact that merely removing the terminal bud can not be depended upon to produce the change.

The complete change of a male tree to one purely female, with fruits of the form of the ordinary dicœcious papaya, is perhaps the most remarkable. A well authenticated case of this character has been reported to the writers and the tree in its present condition has been examined. This tree, which is represented in Plate X, figure 1, produces pistillate flowers. When examined and photographed on January 24, 1913, no evidence could be found of any staminate or hermaphrodite flowers, or of any fruits which appeared to have grown from the latter. All the branches were producing fruit, except one which was too small and weak, being crowded out by the larger members. Dr. John T. Gulick, a scientist of wide reputation, whose studies in evolution published by the Carnegie Institution would alone be sufficient to establish his accuracy of observation and statement, has kindly furnished this station with the history of this tree, which has grown in his garden. His letter reads as follows:

HONOLULU, *May 28, 1913.*

J. E. HIGGINS, Esq.

DEAR SIR: In reply to your request for the history of the papaya tree that changed its habits after being beheaded, I am able to give a few facts.

When the tree was a year and a half or two years old it had produced only staminate flowers, growing on long, dangling branches. It was then 6 or 7 feet high, and as the only use we had for it was as a support for a clothesline, we cut off the leaves and the top of the tree that were in the way of the hanging clothes.

It was not till many months later that we noticed that the new branches were bearing fruit and that the flowers were all pistillate. During the three years that have passed since its head was cut off it has developed 10 branches, some of them being 8 or 9 feet in length, and all of them producing pistillate flowers and fruit. The trunk has also grown in size till now about 18 inches in diameter.

Yours, truly,

(Signed) JOHN T. GULICK.

It will be seen from the above that no known factor has entered as a cause of this change except the removal of the whole top of the tree. Why so marked a result should follow such treatment in this case, while in many others no change is brought about in the character of the flowers, is a question wholly unsettled. The theory of cyclic development proposed by Iorns offers a possible hypothesis. The

question may then be raised as to whether this potentiality to change exists in all parts of the plant at the supposed seasons of susceptibility or whether these stages of development are registered in the different parts of the plant as they are developed, in a manner like bud variations. Nearly all the buds in the upper part of the papaya tree, except the terminal, remain dormant unless some injury occurs to the latter. If these possibilities to change exist as bud variations and it be necessary only to force the buds into growth in order to bring the differences into evidence, then it would follow that, while the removal of the terminal bud at different seasons might produce results, or not, according to the character of the buds immediately below, the cutting at some point lower down might bring about the change. An explanation of these phenomena on the basis of bud variation, however, need not presuppose a cyclic development or the possibility of changing all male trees. There is no lack of evidence that some of the unit characters of a hybrid may become separated in different parts of the plant. A hibiscus hybrid in the experiment gardens of this station produces flowers of different form and coloring on each of several main branches. It is well known that peach trees occasionally produce nectarines. But it is not necessary here to multiply instances of bud variation of which probably no better explanation has been offered than that they represent a character of some antecedent. Whether the facts of changing sex as presented are to be explained on a bud variation hypothesis is a matter of speculation, but the suggestion is made as one perhaps worthy of consideration in seeking a cause of the known facts.

Whatever theories may be entertained as to the causes of the phenomena of changing sex, it still must be admitted that no practical and reliable method is at present available for converting a male tree to one bearing fruit.

THE FEMALE IN SEX CHANGE.

It is worthy of note that no record has been found by the writers, in the literature of the papaya, which would indicate that the female or pistillate tree has ever changed its sex. There are numerous reports of so-called "female" trees bearing hermaphrodite flowers or staminate, but this is apparently an inaccuracy in language, since in such cases no statement is made that a tree once purely pistillate in character has changed to one bearing other kinds of flowers. As has already been pointed out, there are forms with pistillate and other flowers mixed, and these have often been termed in a general but incorrect way "female trees," but such, so far as the records show, have been the same in character throughout their existence.

INHERITANCE OF CHANGE OF SEX.

Some of these changes in sex, when they have been brought about, tend to reproduce themselves in the offspring of such plants. It has been shown that climatic or other conditions may cause male trees to change the character of many of their flowers to hermaphrodite. In the station experiment orchards, where seeds of papaya from many sources have been planted, it has been very apparent that certain lots show a much stronger tendency to produce hermaphrodite flowers than others growing under the same conditions. For example, seeds of a papaya from South Africa were received through the Office of Seed and Plant Introduction, of the United States Department of Agriculture. These were from Singerton, near Hectorspruit, Transvaal.[1]

Prof. J. Burtt Davy, who presented them, states that "these seeds were procured at an altitude of 1,200 feet, subtropical climate, and rather dry." The progeny (Hawaii Station No. 1996) was 33 pistillate trees and 27 males and hermaphroditic males, several exhibiting a tendency to hermaphroditism and bearing fruits. Seeds from one of the trees showing the tendency in a high degree were planted as No. 2599. Of the 16 trees set in the orchard 4 were pistillate, 3 males, and 9 hermaphroditic males. Of the latter, one carried at the time of counting 21 fruits, another 37, and still another 87. Near these were other papaya trees, growing under similar conditions, but presenting only pure pistillate and pure staminate specimens. It would appear, therefore, that such alterations in sex, once established, tend to persist under conditions different from those in which they arose.

ORIGIN OF DIFFERENT FORMS.

Having in mind the facts as outlined above, some discussion may be undertaken as to the probable origin of some of the different forms and manner of sex distribution, to which reference has been made.

Form 3, correæ, has been referred to as a modification of form 2, whereby the aborted pistil becomes developed. It is but a slight modification, because the ovary is nearly always present in the ordinary male.

Form 4, elongata. Although this form is so distinct from a practical point of view, and to casual observation so different from any other, it will be seen that it differs from form 3, correæ, only in three minor particulars: (a) Its flower clusters are greatly shortened; (b) it produces larger fruits than the average correæ; and (c) its staminate flowers do not produce fertile pollen.

In the matter of the peduncle it may be said that practically all degrees of length have been observed here, from the very long to

[1] S. P. I. No. 23915. U. S. Dept. Agr., Bur. Plant Indus. Bul. 153, p. 17.

those about a foot in length, so that it would be difficult to determine whether to class the specimens as correæ or elongata. That the elongata fruits are generally larger need give us no concern, particularly because correæ sometimes bears a fruit as large as the average elongata. The fact that the staminate flowers of elongata have not usually been found to produce fertile pollen appears to furnish some evidence that the evolution has been from correæ to elongata, and not the reverse. This may be an atavistic development toward some hermaphroditic antecedent from which the dicœcious papaya has been derived. It has been mentioned that cold climate increases fructification of the male tree.

In this connection it will be interesting to note a form observed by Correa de Mello and Spruce,[1] and spoken of by them as "the common Carica of the equatorial Andes, where it is cultivated up to 9,000 feet for the sake of its edible fruit." It is there known as "Chamburu." The fruits are described as "8 or 9 inches long and sometimes nearly as broad. The flesh is whitish (not yellow, as in the papaw), soft, and with a pleasant flavor—in cool sites sometimes very acid." Andre[2] states that while traveling in the Andes of Ecuador, near the Colombian frontier, he found two varieties of papaya which were growing in cool territory, and which he cites as examples of the fact that "certain varieties of papaya are more hardy than others." "Two small trees," he continues, "struck my attention in this pretty garden. These two varieties I have not seen anywhere else. The one has an *oblong fruit, very beautiful, cylindrical, mucronate, named Chamburo.*" There can be very little doubt that "Chamburu" of Correa de Mello and Spruce, and "Chamburo" of Andre, are identical. Anyone familiar with the form to which the name elongata has been applied in this bulletin will be impressed at once with its similarity with Chamburu or Chamburo in practically every particular in which the latter is described. The similarity is so strong as to suggest one of two explanations, viz, identity, or that Chamburu represents, in the evolution of the papaya, an early form toward which elongata is an atavism. Correa de Mello and Spruce state that they are unable to identify this with any described species, a fact which is not remarkable, if it be the same as elongata, since *Carica papaya* has always been described from its dicœcious or its andromonœcious forms. In their descriptions of forms of the papaya and other species of Carica, no other form can be found which corresponds to elongata. Elongata has the appearance of having been derived from the male through correæ by an increase in the number of hermaphrodite flowers and a shortening of the peduncles, a process which takes place in cool climates. It is in this connection also that its possible relation to Chamburu of the highlands would be pointed out.

[1] Jour. Linn. Soc. [London], Bot., 10 (1869), p. 11. [2] Rev. Hort. [Paris], 76 (1904), p. 543.

Elongata is now quite widely distributed, but has received very little attention. In many parts of the East it is known as the "Ceylon papaya" or the "Ceylon Long," the seed having been distributed from that center. It is believed to have been sent to Hawaii from Ceylon by Prof. A. Koebele about the year 1896.

To one seeking for a monœcious or hermaphroditic ancestry for the common papaya, the idea may suggest itself that the evolution has been from elongata through correæ to the pure staminate, but on such a hypothesis it is difficult to account for the nonfunctioning staminate flowers of elongata, while those of correæ are so active. Further, if elongata were the more primitive type, it is to be presumed that it would have become more generally distributed at very early times and would have attracted the attention of botanists who, as has been shown, have scarcely mentioned it, while correæ and the strictly dicœcious form of papaya have been described in detail.

Form 5. The sterile hermaphrodite is merely the extreme of barrenness in form 4.

Form 10. The andromonœcious form with the misplaced ovules. This is a peculiar, but significant, arrangement of sex organs. It will be recalled (see p. 22) that the peculiarity of the form is in its occasionally producing ovules on the stamens of its hermaphrodite flowers. There can be no doubt that it has been derived from the ordinary male tree, but its peculiar significance lies in the tendency which it shows to convert some of its stamens into carpels, and, therefore, in the light which it throws upon the peculiarities of the form 6.

Form 6, forbesii. Here the process has gone on so far that the ten stamens of the ordinary male have been reduced to five, the inner five apparently having been changed to carpels. There are several indications of this. (a) The fruit is very deeply furrowed, often showing the newly formed carpels quite separated from each other at the top, and for a considerable distance toward the base. (b) Anthers are often found upon the carpels. (c) Occasionally within a fruit formed of such carpels a body resembling another papaya fruit is to be found (Pl. VIII, inset), which may be regarded as the original ovary which in the ordinary forbesii has been eliminated. (d) One of these irregular and partly separated carpels is sometimes rolled within the others, giving an effect somewhat similar to the one just cited.

It appears probable that forbesii as found to-day has been developed from the ordinary male form, through a process hinted at in form 10, and by conditions similar to those which are believed to have produced correæ. Why the evolution should take place along these two different lines is an interesting question.

Form 7, pentandria. It will be observed from the description that this differs from forbesii in only two particulars. (a) The flower clusters of pentandria are short as in elongata, while those of forbesii are long. This, as has been indicated, is a very minor difference. (b) Pentandria in its purest state produces no pistillate flowers. However, it is highly probable that there are specimens of forbesii which produce only staminate and hermaphrodite flowers.

It naturally occurs to one to inquire whether pentandria has been derived from forbesii by the shortening of the flower clusters, or whether pentandria is the more primitive form. In the literature of the subject, the only reference that has been found to a form, similar to that described, is by André, who mentions a variety as found by him in the Andes of Ecuador, in the identical garden where he discovered the "Chamburo" form (see p. 29). It will be recalled that this was in a high altitude. He says of this second form that it is "smaller with a ribbed fruit of a wholly new appearance," different from anything that he had seen elsewhere. It is there known as "Chiloacan." It seems not improbable that this is identical with the form pentandria which has been described as found in Hawaii. The high Andean altitudes may probably be regarded as the home of the form, for although André found it in a garden, it has not been recorded from other sources which can be regarded as its native habitat. How it came to Hawaii can not be determined, for travelers from these islands have brought or received seeds from almost all tropical and subtropical countries.

Forms 8 and 9 may perhaps be regarded as the results of the crossing of the other forms.

Form 11, ernstii. This it will be seen combines the characters of the ordinary pistillate and those of the elongata. It is well-known that seeds from the hermaphrodite flowers of elongata yield many pistillate plants as well as hermaphrodites and some cœnomonœcious individuals. It is not surprising that a form should be found combining the female and hermaphrodite characters.

Form 12. The above remarks apply equally well to form 12, which differs from the last only in the possession of staminate flowers which are normal to hermaphrodites.

Form 13. Reference has been made to the manner in which this appeared.

ORIGIN OF THE DIŒCIOUS CARICA PAPAYA.

The diœcious *Carica papaya*, being the one most widely known and described and considered as the normal type of the species, has been the subject of the most speculation and study as to its origin. As to its native habitat it is now generally conceded to be of American or Antillean origin. Some writers have regarded it as

indigenous to Asia or Africa, but as De Candolle,[1] Solms-Laubach, and others have clearly pointed out, this view is wholly untenable. There is no record of its having been known before the discovery of America. There is no Sanskrit name for it. The modern Indian names for it are derived from the American word papaya, which in turn is a corruption of the Carib "ababai." Nevertheless, the plant was introduced into the Old World at an early date, for Watt[2] records that seeds were taken from India to Naples in the year 1626. There is some difference of opinion as to the locality of its origin. Correa de Mello and Spruce consider the West Indies as its home, while De Candolle includes also the shores of the Gulf of Mexico as probably within its native habitat. Solms-Laubach inclines strongly to the opinion that its home has been Mexico and Central America. On the whole the continental origin appears more probable.

It is an interesting fact that the species has been found nowhere outside of cultivation except where it appears to be an escape. How it came into existence is a study quite as interesting as that relating to its native habitat. Solms-Laubach proposes the hypothesis that this plant is the product of the fusion of several wild species, and represents the product of the ancient culture of Mexico, although not necessarily the result of intentional hybridizing, but rather of the selection by man of natural hybrids showing valuable characters. It evidently had been in cultivation long before the discovery of America. That some of its near antecedents have been either monœcious or hermaphrodite appears highly probable from the presence of an aborted pistil in the staminate flowers of the male tree; from the frequent cases of development of this aborted organ into a functioning pistil; and from the increasing number of such hermaphrodite flowers under certain conditions of climate and treatment. This tendency shows itself chiefly in the male tree where all the organs are present in some form. In the female where the stamens have entirely disappeared there are, so far as can be learned, no recorded instances of such change to hermaphroditism taking place.

BREEDING WITHIN THE DIŒCIOUS FORMS.

Very little effort has been made to improve the papaya by systematic breeding. There has been some selection on the part of growers who naturally plant the seeds from particularly pleasing fruits. The most of such selection has been with the diœcious papaya and here there is an inherent difficulty even in the way of the scientific breeder. Seed from a pistillate tree will necessarily be a cross of two individuals. The characters of the female plant

[1] Origin of Cultivated Plants. London, 1884, pp. 293–295.
[2] Dictionary of the Economic Products of India. Calcutta, 1889, vol. 2, p. 159.

may be known, but those of the male plant are utterly unknown. The parent stock from which both came may be known, but since there is wide variation in the fruit of two pistillate trees from the same stock it is reasonable to suppose that there will be the same wide variation in the male or staminate trees. The variation between the pistillate trees can easily be determined because their fruits are in evidence and can be tested; but the characters which are inherent in the male or staminate tree, and which will be transmitted by it to its progeny, can be determined only through the long process of actual hand pollination, the sowing of the seed thus produced, and the testing of the fruit. Even then what portion of its excellent or indifferent qualities may have been inherited from its male parent can not be known. Furthermore, the difficulty becomes aggravated by the fact that papaya trees usually degenerate after a few years. At least pistillate trees usually fail to produce good fruit after a few years of growth, although they may continue to produce indifferent fruit for many years. Therefore, even if the inherent characters of the male or staminate tree could be determined with reasonable accuracy, before any such determination could be made the tree would have become too old to be in a reliable state of virility if it degenerates as rapidly as the pistillate tree. The new methods of asexual propagation referred to on page 9 will aid in overcoming this difficulty, but it appears reasonable to suppose that the process of producing a stable variety of good qualities by the use of this dicœcious type would be extremely long and tedious. The hope, therefore, must lie in the use of a hermaphrodite type. Here it is possible to select an individual of known qualities. This may be used as the sole parent stock or may be combined with another parent of known qualities. What mixtures there may be in the individual at the start may not be known; but through repeated selections and the elimination of undesirable characters, it should be possible to produce a reasonably pure strain, provided, of course, that the stock is kept pure by constantly avoiding cross-pollinations with plants of different characters, a process which is necessary in all plants reproduced by seed and whose flowers are subject to accidental cross-pollination.

A further practical difficulty in the use of the dicœcious type, from the standpoint of the papaya grower, as well as the breeder, is the fact that a very large proportion of the trees from any given lot of seed are liable to be staminate, or males, and therefore useless, only a few trees being necessary to pollinate all the pistillate trees. It is impossible so far to distinguish the staminate from the pistillate trees in the early stages of their development. Therefore, in any papaya orchard planted with the dicœcious type, a very large percentage of the trees

must be cut out after they have grown almost to maturity, resulting in unevenness and irregularity in the orchard and much loss of time and space. For this reason, together with the difficulties of breeding, the dicœcious type probably will be largely eliminated.

BREEDING THE HERMAPHRODITE FORMS.

Turning to these forms with more hope of results, some experiments are being conducted. Here it is possible to deal with a single individual mother plant. One of the first facts to be determined is the extent to which the offspring of such a parent may be expected to be fruit-bearing trees. It was known from earlier observation, without any definite experiment, that a large number of the seeds from a fruit of a hermaphrodite flower, produce fruit-bearing trees, either pistillate or, like the parent, hermaphrodite.

A tree was found in a Honolulu papaya orchard producing fruit of excellent flavor. The fruit from which the seed was taken was of the long cylindrical form, but it can not be stated that all the fruits on the tree were of that shape. Its flowers were staminate and hermaphrodite, and so far as observed, of the elongata form. The flowers had not been hand-pollinated and it is therefore impossible to state whether they were autogamously fertilized or otherwise. The seeds were planted May 2, 1910, and later 35 of the young plants were set in the orchard. Of these, F_1, 34 were hermaphrodite and 1 was a staminate tree. The hermaphrodite flowers on most of the trees were of two types, some of the elongata form and others resembling pentandria, with corresponding difference in the fruits. All of the 35 trees were designated as No. 2355, and, according to the method adopted in all our breeding work, the individuals were designated thus: 2355:1, 2355:2, etc. The best of the trees from the standpoint of uniformity of cylindrical shape in fruit was 2355:1, which was also of very good flavor and a reasonably good producer. This was selected for further breeding. Two of its flowers were hand-pollinated each with its own pollen and protected from all possible allogamy. The seeds collected from these two fruits were planted as No. 3198.

At this writing there are of this F_2, 343 trees living and old enough to have exhibited sex characters, some of them having done so for several weeks past. The individuals judged by the characters apparent to date are as follows:

Pistillate trees	98
Elongata	61
Pentandria	45
Elongata, pentandria, and intermediate	55
Pentandria and pistillate	1
Fruit bearing but not determinable in form	62
Total fruiting exclusive of correæ	322

Staminate	18
Correæ	3
Total	343

It will thus be seen that, exclusive of correæ, approximately 94 per cent of the trees are fruit bearing. This is an encouraging result, so far as the elimination of the males is concerned. It is not probable that the 61 designated as elongata will continue to produce flowers and fruits of this form exclusively. It is probable that some of the pentandria form of flowers and fruits will appear, but it is hoped that it will be possible to develop a pure strain of uniform shape. It is probable that the progeny will continue to include pistillate as well as hermaphrodite trees. Whether it will be necessary to have two forms of a variety, one borne on the pistillate tree and another on the hermaphrodite, can not be determined at present. If this should be the case, it would necessitate, in marketing, two packs, which might be sold under different varietal names. This will be no serious disadvantage, provided uniformity can be maintained in each form. There are two ways, however, in which it is conceivable that a uniformity might be maintained, common to the hermaphrodite and the pistillate alike. Among the pistillate trees of No. 3198 were several with elongated cylindrical ovaries, like those found on the hermaphrodite elongata, which would indicate that this particular shape of ovary and resulting fruit is not necessarily confined to hermaphrodites.

Another conceivable means of establishing uniformity would be in the selection of pistillate trees whose fruits are angular like those of the hermaphrodite pentandria.

HERMAPHRODITISM IN LYCHNIS DIOICA.

In this connection the experiments of Shull [1] on *Lychnis dioica* are interesting and important. Hermaphrodite individuals appear as mutants in *L. dioica*. These the author concludes are modified males and are of two kinds, distinguished as "genetic" and "somatic" hermaphrodites.

> When the genetic hermaphrodites are used as pollen parents, either when self-fertilized or in crosses with females, their progeny consists of females and hermaphrodites. When they are used as pistil parents and fertilized by normal males, they produce females and normal males.
>
> Somatic hermaphrodites may be externally indistinguishable from genetic hermaphrodites, but when used as pollen parents they produce no hermaphrodite offspring, but only females and normal males.

These somatic hermaphrodites, however, were found to be rare in comparison to the genetic hermaphrodites. The author has shown

[1] G. H. Shull. Bot. Gaz., 49 (1910), No. 2, pp. 110–125; 52 (1911), No. 5, pp. 329–368.

in the case of *L. dioica* that the eggs can not transmit the hermaphrodite character to the male offspring. This character can be carried only through the pollen.

"Among the offspring of genetic hermaphrodites," he continues, "were a small number of male mutants, which on breeding proved to be normal males." In the case of 2355 referred to (see p. 34) there is one male mutating from the hermaphrodite form and much has been said of hermaphrodites appearing as mutants from ordinary males. Such sex mutants appear to occur not infrequently in the papaya.

BREEDING WITHIN THE ANDROMONŒCIOUS FORMS.

Very limited experience has been afforded in crossing hermaphrodite flowers of the correæ form from trees of different origin. In one instance such a cross was made, resulting in several pistillate trees, a few staminate, and many hermaphrodite of the elongata form out of 73 trees in all. This is interesting evidence which would appear to indicate that elongata and correæ differ only in degree.

Another result of this cross is worthy of note. One of the pistillate trees of this progeny produces an ovary and a resulting fruit very closely resembling those of elongata form (Pl. X, fig. 2), which would again indicate that this shape of ovary is not necessarily confined to a hermaphrodite flower.

CROSSING THE DIFFERENT FORMS.

POSSIBILITIES AND LIMITATIONS.

It may often be desirable to combine the characters of individuals of the different forms. To test the possibilities of pollinations, seventeen different combinations of pollen and stigma have been tried. The table (p. 27) shows the number of cases in which each of these combinations was tried in the experiment and the number of successes resulting. The results of pollination, designated in the second column as "successful" and "unsuccessful," will show at a glance whether any successes have been attained in any particular cross. Some of the successful pollinations have been repeated many times since the close of this specific experiment. It should be stated also that the pollinations on any given tree were not made in a single day, usually not more than one flower being available on any one day. This reduces the influence of weather conditions which also were chosen as favorably as possible. The usual precautions were taken to prevent the access of pollen other than that designated. Emasculation was practiced where required and flowers covered with cotton sacks which had been immersed in warm paraffin.

Table showing pollinations and results.

Pollination number.	Successful or unsuccessful.	Description of pollination.	Tree used as pistil parent.	Number of flowers pollinated.	Number of fruits set.	Number of failures.
First	Successful	Hermaphrodite elongata flower with its own pollen.	2125:3	4	4	0
			2123:6	5	0	5
Second	Unsuccessful	Hermaphrodite elongata flower with pollen from ♂ flower in same cluster.	2091:1	7	0	7
			2091:11	9	0	9
Third	Unsuccessful	Hermaphrodite elongata flower with pollen from ♂ flower in another cluster.	2168:4	6	0	6
Fourth	Successful	Hermaphrodite elongata flower with pollen from ♀ flower from another elongata tree.	2355:1	5	4	1
			2355:6	7	6	1
Fifth	Unsuccessful	Hermaphrodite elongata flower with pollen from ♂ flower from another elongata tree.	2355:7	7	0	7
			2355:2	5	0	5
Sixth	Successful	Hermaphrodite elongata flower with pollen from ♀ flower of correæ.	2461:6	23	1	22
			2493:1	33	0	33
			3198:11	3	3	0
			3198:14	4	2	2
Seventh	Successful	Hermaphrodite elongata flower with pollen from a ♂ flower from male tree (form 2).	2491:6	26	0	26
			2493:6	18	0	18
			3198:19	3	3	0
			3198:20	3	3	0
			3198:21	2	2	0
Eighth	Successful	Pistillate tree flower with pollen from a ♀ flower from the elongata tree.	2491:1	25	[1] 0	25
			2491:2	14	[1] 0	14
			2087:3	1	1	0
			2087:16	1	1	0
			3198:1	1	1	0
			3198:2	1	1	0
			3198:3	2	0	2
			3198:4	2	2	0
			3198:5	1	1	0
			3198:7	1	0	1
			3198:10	1	1	0
			3198:12	1	0	1
Ninth	Successful	Pistillate tree flower with pollen from a ♂ flower from the elongata tree.	2491:3	23	0	23
			2491:5	10	0	10
			3198:1	2	2	0
			3198:2	1	1	0
			3198:3	1	1	0
			3198:4	2	2	0
			3198:5	2	2	0
Tenth	Successful	Pistillate tree flower with pollen from ♂ flower from male tree.	1996:11	2	2	0
			1996:37	1	1	0
			1982:22	1	1	0
			3198:6	2	2	0
			3198:7	2	2	0
			3198:8	3	3	0
			3198:9	1	1	0
Eleventh	Successful	Pistillate tree flower with pollen from ♀ flower from a tree of correæ form.	2491:9	11	[1] 0	11
			2491:11	6	[1] 0	6
			3198:12	3	3	0
			3198:16	2	2	0
			3198:17	1	1	0
			3198:18	2	2	0
Twelfth	Successful	Hermaphrodite flower of correæ with pollen from ♀ flower of elongata.	2461:15	11	1	10
			2476:9	8	0	8
			3198:13	2	1	1
			3198:15	6	5	1
Thirteenth	Unsuccessful	Hermaphrodite flower of correæ with pollen from ♂ flower of elongata.	2459:1	18	0	18
			2493:2	27	0	27
			2494:5	23	0	23
			2494:7	24	0	2
			2979:1	8	0	8
Fourteenth	Successful	Hermaphrodite flower of correæ with pollen from ♂ flower of male tree (form 2).	2474:3	23	3	20
			2474:4	25	3	22
			2474:10	24	2	22
			2979:3	8	0	8
Fifteenth	Successful	Hermaphrodite flower of correæ with its own pollen (hand pollinated).	2474:12	16	0	16
			2474:13	21	1	20
			2979:2	8	1	7
Sixteenth	Successful	Hermaphrodite flower of correæ with its own pollen (sealed in sack but not hand pollinated).	1996:27	1	1	0
			2494:5	1	1	0
			2979:2	4	0	4
			3198:15	7	7	0
Seventeenth	Successful	Hermaphrodite flower of correæ with pollen from ♀ flower of another correæ.	2090:6	1	1	0

[1] It was later discovered that the flowers of these trees failed to become fecundated with any pollen that was tried artificially.

From the data contained in the above table it is possible to draw some conclusions and to point to other probabilities indicated. It will be observed that the only pollinations which were wholly unsuccessful were Nos. 2, 3, 5, and 13. These were in every case examples of the use of pollen from the staminate flowers of the elongata form and include all such cases except the ninth class of pollination. In the ninth, where pistillate flowers of different individuals of No. 3198 received such pollen, fertilization took place. This pollen was all taken from one tree, and the instance constitutes the only case on record at the station where pollen from the staminate flowers of elongata was successful in fertilization. It seems probable, therefore, that the stamens of such flowers in most trees are infertile. In the earlier work on the papaya here these indications had not developed, and, believing the staminate to be functioning flowers, this elongata form was spoken of as monœcious. While the above results show that this was a correct supposition for at least the one tree from which pollen was taken to No. 3198, so many examples of the failure of such pollen are on record here, that, at least for the present, elongata must be described as usually hermaphrodite.

A further fact brought out by the figures of the table is that certain individuals and stocks exhibit peculiarities of their own in relation to pollination. The stocks of Nos. 2491, 2493, and 2494 were not fertilized with any pollen that was applied to them, except in the case of 2494:5, which was fertilized by its own pollen within a sack. This individual peculiarity was not discovered in the earlier experiments which seemed to indicate that the seventh and the eleventh classes of pollinations were not successful. The later experiments have shown that the failure of the earlier trials was due to such peculiarities of stocks or of individuals. The presence of these peculiarities suggests great caution in generalizing, and results presented here, as in the case of the earlier reports, are offered merely as cumulative data.

However, it is evident that any of the forms may be crossed. What the results will be in the sex characters of the offspring has been determined only in part. If the breeding is confined to the purely diœcious forms, there are, so far as the records show, no instances of the appearance of truly hermaphrodite forms by sudden mutations. Hermaphrodite flowers may appear among the staminate, thus giving rise to andromonœcism, as has been stated.

COMBINING DIŒCIOUS WITH HERMAPHRODITE FORMS.

Although it is best in practical papaya culture to avoid the diœcious varieties for reasons that have been pointed out, it is nevertheless true that some of these have highly valuable characters which it would be desirable to introduce into a hermaphrodite form. Obviously in any cross which is to combine in part the characters of indi-

viduals of these two forms, the pollen must be taken either from the staminate tree to the hermaphrodite flower or from the hermaphrodite flower to the pistillate tree. That is to say, the seventh or eighth type of pollination must be employed. There is objection to the seventh on the ground that it employs a male parent, many of whose characters are unknown, because it bears no fruit, and further because the hermaphroditic character would probably be lost. In this latter particular the experiments have not been carried far enough to determine the sex characters of the offspring of such a cross for the reason that the first attempts to impregnate the ovary of the hermaphrodite flower with pollen from the male tree resulted in repeated failures, for reasons which have been referred to (see p. 38). Since the hermaphrodite is apparently a modified form of the male, or vice versa, it would not be surprising to find that sex results in this cross would correspond rather closely with those which Shull has found in *Lychnis dioca*. Should that prove to be true, no hermaphrodites would result from such a cross, unless it be as an occasional mutant.

If this be the case there would remain the other alternative, viz, to use the hermaphrodite flower as the male parent, applying its pollen to a pistillate tree of known characters. No experiments of this kind have been completed in which a pistillate tree of purely dicœcious origin has been used. A similar experiment in which a pistillate tree from hermaphrodite stock was used as the female parent is interesting. It is possible that results would not be different had the pistillate tree been of pure dicœcious stock. Seeds were collected from a chance fruit of unknown origin and planted as No. 2087. The fruit was chosen purely for its flavor and other pleasing qualities, and not with a view to the specific experiments which later developed. Seventeen trees were planted out when too young to exhibit sex characters. These developed into 12 pistillate trees, 4 hermaphrodite, and 1 staminate. When they came into bearing No. 2087:3 ♀ was crossed with No. 2087:17 ☿. The F_1 from this cross was planted under accession No. 2491. At the time the trees were examined there were 5 pure pistillate individuals, 9 with more or less tendency to hermaphroditic characters, and 1 staminate. The latter produced only staminate flowers. Of the 9, there was one normal hermaphrodite of the elongata form, and another the same except in the case of two fruits. The remainder exhibited flowers and fruits of varied form, some with the stamens reduced to five in number, and producing fruit of the pentandria form. In others certain of the carpels failed to develop in the fruit, due to defective stigmas, thus giving rise to gibbous fruits. The stigmas and the anthers were both inclined to irregularity of position, anthers being found on the carpels.

Fruits of elongata, of pentandria, and of various other forms could be found upon the same tree.

A similar cross was made between 2087:16 ♀ and 1191:1 ☿ (elongata). The seeds resulting from this cross were divided into two lots on the basis of color and were planted as 2493 and 2494, the former being gray and the latter black. The resulting population in the case of 2493 presented 11 pistillate, 1 normal hermaphrodite of elongata form, 3 abnormal hermaphrodites like those described in the last cross, 3 males (nonfruit-bearing), and 1 hermaphroditic male. The individuals of 2494 were 6 pistillate, 1 male, and 2 hermaphroditic males.

The above figures, representing results in sex, are to be understood as applying to the trees which were planted, there being in nearly every case many more trees than space could be found to plant.

STOCKS NOT SHOWING ANY FERTILIZATION.

A noteworthy fact developed in regard to the stocks of 2493 and 2494, as referred to above. The flowers of a number of the different pistillate and hermaphrodite trees were hand-pollinated with pollen from different sources, but in every instance failed to develop. The pollen used in these instances was taken from the hermaphrodite flowers of correæ, from pure staminate trees, and from hermaphrodite and supposed staminate plants of the elongata type.

PARTHENOCARPY.

Some of these trees were found to be capable of a parthenocarpic development of fruit. Certain pistillate flowers were covered with paraffined sacks to prevent pollination and developed within the sacks until the latter were broken by the force of growth. Such fruits were found to be seedless. One of these is illustrated in Plate IX, figure 2.

A further peculiar fact is that these trees if not operated upon in any way received pollen from some source which satisfied their needs and resulted in seed production. That the failure of those hand-pollinated was not due to errors of technique seems certain, since the method and the time were the same as were used successfully in so many other cases with flowers of the same external structure.

A tree in the Mount Tantalus orchard of the station was found to be producing seedless fruit. This is a pistillate tree of hermaphrodite stock. On one occasion six fruits were cut open and found to be without any seeds. On another occasion seven were cut open and all were seedless except one which contained three seeds. Several of the flowers were covered in paraffined sacks and were hand-pollinated when the stigmas appeared to be ready for the reception of pollen, the sacks being again put over the flowers. Several other flowers on the same tree were covered with the sacks and left without

any pollen. All of these flowers, pollinated and unpollinated alike, produced fruit but no seed. Those unpollinated furnish another clear case of parthenocarpy. In the case of those that were hand-pollinated the pollen appears to have been wholly without influence, being in this respect unlike those of Nos. 2491, 2493, and 2494, referred to above. It is also fair to conclude that seedlessness in this tree was not due to a lack of fertile pollen, because pollen was actually applied to the stigmas, and also because an abundant supply of effective pollen was present in the orchard, as evidenced by the presence of many seeds in the fruits of other trees.

Other instances of parthenocarpy in papaya have been observed.

No. 1996:37, a pistillate tree of a dicœcious stock whose male trees showed some tendency to bear hermaphrodite flowers, exhibited this phenomenon. Several of its flowers which were sealed in paraffined sacks to prevent pollination grew into normal fruits and after three months were cut open and found to be seedless. On the same tree other fruits from flowers which had not been sealed were found to contain many seeds. It is apparent that the carpels of these flowers were capable of development with or without the influence of pollen.

In the above it will be observed that the fourteenth and fifteenth pollinations proved successful in only a few cases. It is to be noted that the mother trees in all these instances were of the No. 2474 stock, which was the progeny of the No. 1996 stock which exhibited the tendency to parthenocarpy, although it did not refuse pollination. This suggests the transmissibility of parthenocarpic tendencies.

It is apparent, therefore, that parthenocarpy is not rare in the papaya, but that it is not the rule is proved by a large number of observations and experiments. Pistillate flowers of most papaya trees will fail to set fruit if prevented from receiving pollen.

PARTHENOGENESIS.

Cases of parthenogenesis have been watched for but none has been recorded. In one instance where no pollen came in contact with the stigma the fruit was found to contain one seed, but this proved to be infertile.

HYBRIDIZATION OF CARICA.

It is probable that there has been considerable hybridizing of Carica by natural means and the genus has not been wholly neglected by plant breeders.[1] *C. cundinamarcensis* has been crossed with the pollen of *C. papaya*. Also *C. cauliflora* as a mother plant has been crossed with *C. papaya*. Van Volxem[2] crossed *C. erythrocarpa* with the pollen of *C. cundinamarcensis* and then proceeded to inbreed by crossing his new hybrid as a mother plant with *C. cundinamarcensis*.

[1] cf. Solms-Laubach and also André in articles referred to above.

[2] J. van Volxem. Gard. Chron., n. ser., 14 (1880), p. 729.

C. papaya has been hybridized with *C. gracilis*, the latter as the male parent. In the orchards of the Hawaii station there are trees which are believed to be natural hybrids of *C. papaya* and *C. peltata*. Attempts made at this station to cross *C. papaya* with *C. quercifolia* have failed.

AN ATTEMPT TO BREED A HERMAPHRODITE PAPAYA.

Mr. John Scott,[1] who had observed plants apparently of the forbesii form but had not seen those of elongata or pentandria, was impressed with the idea that it would be possible to increase the number of hermaphrodite flowers and shorten the peduncles until a truly hermaphrodite race would be attained. The work was begun but was unfortunately terminated by the early death of Mr. Scott.

IDEALS IN BREEDING THE PAPAYA.

There seems to be no good reason to doubt that it will be possible to breed a papaya combining at least many of the most desirable characters and to hold the variety reasonably stable by the same means as are employed in maintaining seed varieties of vegetables and garden flowers. This presupposes segregation or hand pollination in either case, the latter being the method which most breeders will be compelled to follow because of the proximity of other varieties over which they have no control. The simplicity of hand pollination in the papaya and the large number of seeds resulting from one operation renders it a very practical means even for commercial seed production.

It may be well to outline here some of the ideals which the breeder should have in mind in his search for Mendelian characters which may be combined.

1. *Vigor of tree.*—It is important with the papaya, as with other species, to use vigorous individuals as parent stocks.

2. *Early and low fruiting habits.*—There is a wide variation in the plants in this respect, some producing no fruit on the first five or six feet of the stem, while others bear fruit which almost touches the soil. It is believed that this is a character which may be transmissible, and the advantage of early and low-bearing trees is obvious.

3. *Freedom from the branching habit.*—Trees that produce side branches freely require considerable pruning to prevent the numerous new shoots from taking the nourishment which should go to the fruit.

4. *Productivity but not excessive bearing.*—Trees that have long bare spaces on their stems and those whose fruits are so numerous as to crowd each other should be avoided in favor of such as have the fruits well spaced with just sufficient room to mature normally.

[1] Trans. Bot. Soc. Edinburgh, 11 (1873), pp. 287–288.

5. *Hermaphroditism.*—The reasons for preferring hermaphrodite stock have already been pointed out. The stocks may continue to be gynodiœcious[1] and to a very limited extent even triœcious,[2] but the number of male trees can be kept very small.

6. *Suitable size in fruit.*—The size that will be most desirable will depend upon the purpose to which the variety is to be put. For home use or for the fresh fruit market the extremely large varieties are not popular, and the breeder of table varieties will not, therefore, attempt to originate such forms. On the other hand there is a place for these, if the fruit is to be grown as feed for poultry or other live stock. For papain production, other things being equal, the large fruit would be best.

7. *Yield in papain.*—Where the production of papain is made an industry there can be little doubt that the average yield of this drug could be very greatly increased by judicious breeding.

8. *Uniformity of shape.*—The breeder must seek to establish varieties in which there will be reasonable uniformity of shape as well as symmetry and smoothness. It is not necessary that all varieties be alike, but there must be uniformity in pack. In breeding from hermaphrodite trees there will be a large number of pistillate trees in the offspring. Although the long form is not necessarily confined to the hermaphrodite tree, as pointed out above (see p. 34), nevertheless pistillate trees do not usually yield fruit of this shape. For this reason the breeder may think it best to work for two forms of fruit—the long, tending to cylindrical, for the hermaphrodite, and the obovoid for the pistillate. The fruits of such an orchard would be packed as two varieties.

9. *Uniformity in ripening.*—This is an important consideration. Some papayas ripen and decay at the outer end or the point while the inner half near the stem is too green to be eaten. The ideal papaya in ripening shows its first yellowing along the ribs about midway of the fruit and ripens uniformly toward each end.

10. *Coloring before softening.*—Some fruits ripen with very little color, while others acquire a beautiful golden yellow when still hard, and may be kept for several days. The latter are so much more attractive on the table and in the market that they should be sought after in breeding.

11. *Color of flesh.*—Those of pale whitish flesh must give place to the fruits of yellow, pink, or red color within. Recently some have been grown at this station with a quite decidedly reddish hue.

12. *Easily separable placenta.*—If the placenta adheres tightly to the inner portions of the fruit and is more or less buried in the flesh, it is difficult to remove the seeds without marring the appearance of the

[1] Containing hermaphrodite and pistillate individuals.

[2] Containing hermaphrodite, pistillate, and staminate individuals.

fruit. On the other hand, it is a distinct advantage if the placenta and seeds can be readily removed without scraping the flesh.

13. *Flavor.*—This is without doubt the most important factor to be considered. Experience has shown that specific flavors can be transmitted, and this affords the breeder an opportunity to originate and establish varieties of high quality. This flavor can not well be described, but is easily recognized and appreciated.

14. *Keeping qualities.*—The ideal papaya should be a good keeper, and this character has been found often enough in the fruit of individual trees to lend much encouragement to the breeder.

INSECT PESTS.

By D. T. Fullaway.

Insect pests give little trouble in papaya cultivation. About the only harmful insects noted on this valuable fruit tree, in the course of several years that it has been grown continuously in large numbers on the station grounds and almost daily under observation, is a red mite (*Tetranychus* sp.), which occurs in small and very scattered colonies on the underside of the leaves and occasionally in excessively large numbers on the fruits, and a caterpillar (the larva of the recently introduced moth *Cryptoblabes aliena*), which feeds under a web on the floral stems and beneath the flower clusters of this and many other economic trees and plants. Neither insect is injurious in the sense of seriously affecting the crop of fruit for which the plant is grown. The mite would probably be serious, but it seems to be held in check by the many predaceous enemies of the small leaf-infesting forms which are common on imported economic plants. Some of the armored scales, like *Saissetia nigra*, are occasionally found on the trunk and foliage, but only incidentally. Cutworms (*Agrotis ypsilon*) also occasionally attack seedling plants, but this pest is so easily controlled in the case of the papaya that it is almost negligible as a factor in papaya cultivation.

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